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On the Polarization of Gamma Ray Bursts and their Optical Afterglows

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Abstract. The polarization of the optical afterglow (AG) of Gamma-Ray Bursts (GRBs) has only been measured in a few instances at various times after the GRB. In all cases except the best measured one (GRB 030329) the observed polarization and its evolution are simple and easy to explain in the most naive version of the "Cannonball" model of GRBs: the "intrinsic" AG polarization is small and the observations reflect the "foreground" effects of the host galaxy and ours. The polarization observed in GRB 030329 behaves chaotically, its understanding requires reasonable but ad-hoc ingredients. The polarization of the γ-rays of a GRB has only been measured in the case of GRB 021206. The result is debated, but similar measurements would be crucial to the determination of the GRB-generating mechanism.

Key words: gamma rays: bursts—afterglow polarization: general

1. Introduction

Spectropolarimetric measurements of radiations from astronomical objects are an important diagnostic tool of their production mechanism. Gamma Ray Bursts (GRBs) are not an exception. For these phenomena one must distinguish between two observables: the polarization of the "prompt" γ-rays of the GRB itself, which has been measured in just one instance (GRB 021206; Coburn and Boggs 2003) and the polarization of the GRB afterglows (AGs), observed at optical frequencies in a handful of cases (GRB 990510: Wijers et al. 1999; Covino et al. 1999; GRB 990712: Rol et al. 2000; GRB 010222: Bjornsson et al. 2001; GRB 011211: Covino et al. 2002; GRB 020405: Bersier et al. 2002; Masetti et al. 2003; Covino et al. 2003a; GRB 020813: Barth et al. 2003; Covino et al. 2003b; Gorosabel et al. 2003; GRB 021004: Rol et al. 2003; Wang et al. 2003; GRB 030329: Efimov et al. 2003; Magalhaes et al. 2003; Covino et al. 2003c; Greiner et al. 2003).

In this paper we are primarily concerned with the polarization of optical AGs, though we first comment on that of a GRB itself. We shall conclude that, while (difficult) convincing measurements of the polarization of GRBs would be decisive in establishing the *mechanism* generating GRBs, the measurement of the polarization of AGs is unlikely (at least in the CB model) to shed much light on their understanding.

2. Observational results

The first, and so far the only measurement of the prompt polarization of a GRB was recently reported. Using the RHESSI (Reuven Ramaty High Energy Solar Spectroscopic Imager) satellite, whose primary mission is to look at the Sun in the γ-ray band, Coburn and Boggs (2003) discovered the extremely bright GRB 021206, and measured a very large linear polarization of its prompt γ-rays: $\Pi = (80 \pm 20)\%$. This polarization measurement has been criticized by Rutledge & Fox (2003), who obtain an upper limit $\Pi < 4.1\%$ at 90% confidence from the same data. Boggs & Coburn (2003) have criticized the critique, and announced a systematic reanalysis. We cannot judge this controversy, nor its likely outcome.

The first polarimetric measurement of a GRB's optical AG was that of GRB 990123 (Hjorth et al. 1999) and was consistent with zero. The eight later optical-AG observations (cited in the Introduction) were positive detections of a small linear polarization, typically $\Pi < 3\%$.

The recent measurements of the AG of GRB 030329 —at a redshift $z = 0.1685$ the nearest GRB after GRB 980425— made with an unprecedentedly frequent sampling in time, show rapid variations in the magnitude and angle of its linear polarization (Greiner et al. 2003). These variations do not appear to be clearly correlated with the observed deviations of the optical AG fluence from a smooth behaviour.

With the exception of GRB 030329, for which the late-time AG data may be "contaminated" by its prominent associated supernova (Dado, Dar & De Rújula 2003c; Stanek et al. 2003, Hjorth et al. 2003), in all AGs wherein a non-zero polarization was measured at late time, its value and position angle were consistent, within errors, with the polarization induced by dust in our own Galaxy along the

line of sight to the GRB (e.g. Covino et al. 1999, 2003; Lazzati et al. 2003a). In three cases for which there are measurements at various times (GRBs 020405, 020813, 021004) the level of polarization and/or the position angle evolved towards its late-time constant value. These are strong indications that the intrinsic polarization of the source tends with time to a small value.

3. The polarization of the γ-rays of GRBs

Two different mechanisms have been discussed as the possible dominant sources of the γ-rays of GRBs: *Inverse Compton Scattering* (ICS) and *synchrotron radiation* (SR). The first mechanism naturally results in a sizeable polarization, while the second one does not.

Shaviv & Dar (1995) hypothesized that the γ-rays of a GRB are produced by ICS of ambient photons by electrons partaking in the bulk motion of highly relativistic, very collimated jets. The jets would be emitted in mergers of compact stellar objects that lead to a gravitational collapse. If the electrons' Lorentz factor is $\gamma \sim 10^3$, target photons of energy ~ 1 eV are upscattered to the observed energies, higher by a factor $\sim \gamma^2$. The outgoing photons are forward-collimated within a beam of characteristic angular aperture $\sim 1/\gamma$. At an observer's angle θ, the predicted polarization is:

$$\Pi(\theta,\gamma) \approx 2\,\theta^2\,\gamma^2/(1+\theta^4\,\gamma^4), \qquad (1)$$

which, for the probable viewing angles, $\theta \sim 1/\gamma$, is naturally large (Shaviv & Dar 1995).

Contrariwise, the expected polarization vanishes (see e.g., Medvedev and Loeb 1999; Lyutikov, Parviev & Blandford 2003) if the γ-ray generating mechanism is that of *fireball* models: SR from shock-accelerated electrons moving in the highly entangled magnetic field created by a relativistic shell interacting with the circumburst medium (Katz 1994a,b). This is the case both for GRBs produced by honest-to-goodness (i.e. spherical) fireballs and for "collimated fireballs" viewed from the traditionally-adopted on–axis viewing position (Rhoads 1997, 1999; Sari, Piran & Halpern 1999; Frail et al. 2001; Berger et al. 2003a; Bloom et al. 2003).

A GRB polarization large enough to be measurable, such as that observed in GRB 021206 (if it is not in error) would very clearly advocate in favour of ICS, as opposed to SR, as the mechanism generating the γ-rays of a GRB (Dar & De Rújula, 2003; see also the later work[1] of Lazzati et al. 2004). Interestingly, other authors reach the opposite conclusion. Nakar, Piran & Waxman (2003), for instance, state: "the recent detection of very high linear polarization... suggests strongly that these γ-rays are produced by synchrotron emission of relativistic particles."

SR from a power-law distribution of electrons $dn_e/dE \sim E^{-p}$ in a *constant* magnetic field can produce a large polarization, $\Pi = (p+1)/(p+7/3)$, that is $\approx 70\%$ for $p \approx 2.2$. But a collisionless shock acceleration of the electrons requires highly disordered and time varying magnetic fields (for a recent review see, e.g. Zhang & Meszaros 2003, for a dissenting view on this point, see Lyutikov, Pariev & Blandford 2003). Only under very contrived circumstances —such as geometrical coincidences and unnaturally ordered magnetic fields— can shock models of GRBs produce a large linear polarization. In our opinion, this is what recent articles (Eichler & Levinson, 2003; Waxman, 2003; Nakar, Piran & Waxman, 2003) on the subject show, although it is not what they say.

Another problem with a SR origin of a large polarization in shock models is that if synchrotron self-absorption is invoked to explain the low-energy spectral shape of GRBs, then the linear polarization is (Ginzburg and Syrovatski, 1969; Longair 1994) $\Pi = 3/(6p+3) < 12\%$, parallel to the magnetic field. Since most of the photons of GRB 021206 had energies below its peak energy (larger than 1 MeV), synchrotron self absorption and/or an entangled magnetic field should result in a polarization $\Pi < 12\%$.

4. The polarization of AGs in fireball models

Linear polarizations of the order of a few percent were proposed to arise from causally-connected magnetic patches (e.g. Gruzinov & Waxman 1999), from homogeneous conical jets (Gruzinov 1999; Ghisellini & Lazzati 1999; Sari 1999) and from structured jets viewed off-axis (Rossi, Lazzati & Rees 2002). The observations have been interpreted as evidence for a small intrinsic linear polarization of the optical AG of GRBs (Lazzati et al. 2003a).

5. The CB model

In this model long-duration GRBs are produced in core-collapse supernova (SN) events[2]. An accretion disk around the newly-collapsed core is supposed to be made by stellar material that has not been efficiently ejected. In analogy with processes seen to occur in quasars and microquasars, the subsequent periods of violent accretion of disk material lead to the bipolar ejection of relativistic blobs of ordinary matter: *cannonballs*. Each CB generates one pulse of a GRB as it crosses and Compton up-scatters the "ambient light" surrounding the progenitor star. This model is very successful in its very simple description of the properties of GRBs (Dar & De Rújula 2000a,b, 2003).

The CBs initially expand (in their rest system) at a velocity comparable to, or smaller than, the speed of sound in a relativistic plasma ($c/\sqrt{3}$), so that the jet opening angle —subtended by a CB's radius as observed from its

[1] The "sociological" aspects of this work have been criticized in De Rújula (2003).

[2] Dar & De Rújula (2003) argue that type Ia SNe are responsible for short-duration GRBs, while core-collapse SNe (Types Ib, Ic and II) are the progenitors of long GRBs.

emission point[3])— is $\alpha_j < 1/(\gamma_0\,\sqrt{3})$. An observer sees the "Doppler-favoured" jet, travelling at a small angle $\theta = \mathcal{O}(1/\gamma)$ relative to the line of sight. Typically $\theta > \alpha_j$, so that the jet's opening angle can be neglected and the observer's angle is the *only* relevant one. That is why the prediction of Eq. (1) for a narrow jet is naturally incorporated in the CB model[4].

6. AGs and their polarization in the CB model

In the CB model the AG —unlike the prompt GRB— is generated by electron SR in the disordered magnetic mesh permeating a CB (this was the only similarity between the CB model and the fireball models, before the latter significantly evolved).

As a CB moves through the interstellar medium (ISM), it gathers and scatters its constituent electrons and nuclei. These generate within the CB chaotic magnetic fields that accelerate all charged particles, in a "Fermi" acceleration process that was conjectured in Dar (1998) and has been numerically studied by Frederiksen et al. (2003). Their results, based on "first principles" (Maxwell's equations and the Lorentz force) show that the process of acceleration does not involve the formation of any shocks, contrary to the customary basic assumption of fireball models.

The AG is the synchrotron radiation from the accelerated electrons, in the CBs magnetic field, whose magnitude is predictable (Dado et al. 2002a). This model is very successful in its description of the properties of X-ray, optical (Dado et al. 2002a) and radio AGs (Dado et al. 2003a).

6.1. Intrinsic polarization

The naive expectation is that, since the magnetic field within a CB is disordered, the *intrinsic* AG polarization ought to be small, since it would result from a fractional "order" in a disordered field. The currents induced by the ISM —which in a CB's rest system impinges onto the CB as a one-directional relativistic wind— may depend on the ISM's varying density, and have a non-vanishing "convective" component. The CBs are viewed at an angle relative to their direction of motion, so that symmetry considerations do not prevent the possible existence of a small and time-dependent intrinsic polarization.

It would be very difficult, and arguably uninteresting, to estimate the precise magnitude of a CB's intrinsic polarization. Here we deal with this problem in the most expedient fashion: setting the intrinsic polarization to zero and studying phenomenologically whether this simplest ansatz is tenable. The case of GRB 030329, with its very time-dependent polarization, will force us to envisage the possibility (but not the unavoidable conclusion) of the existence of small but non-vanishing intrinsic polarizations.

6.2. Extrinsic (or foreground) polarization

The subject of the AG polarization is rendered messier by unavoidable, *extrinsic* time-varying contributions, expected and observed to be of the same order of magnitude as the measured polarization levels. These effects are induced by dust along the line of sight to the GRB. The total extrinsic polarization results from the cumulative effects of the dust in the GRB's host galaxy and in our Galaxy. In the CB model, moreover, the host-induced contribution to the polarization is time-dependent, since the CBs responsible for the GRB and for its AG travel distances of the order of kiloparsecs during the time the AG is observed. In this journey, CBs ought to depart from the dustier central star-forming region of the host galaxy, where the event originates. They may also exit a "super-bubble", to encounter enhanced and varying dust concentrations.

6.3. Total polarization

The polarization of the AG light from each of its uncorrelated sources (intrinsic to the CB, the underlying SN and that induced by the magnetized ISM dust of the host galaxy and ours) is linear and small. Let Q_i and U_i be the customary (normalized) Stokes' parameters, characterizing linearly, partially polarized light, with i an index running over the three sources. Let $Q = \Sigma\, Q_i$ and $U = \Sigma\, U_i$. The cumulative degree of linear polarization and its angle are simply $\Pi \simeq (U^2 + Q^2)^{1/2}$ and $\tan 2\chi \simeq U/Q$.

Only the Galactic contribution to the AG polarization is fixed in magnitude, angle and time. The polarization of the SN light is time dependent and may be approximated by that of SN1998bw (Patat et al. 2001). A priori we cannot tell whether a potential intrinsic polarization is a function of time. The time dependence of the host-galaxy's contribution —due to the CB's motion in the host galaxy— requires a more detailed discussion.

6.4. The polarization induced by the host galaxy

Let γ_0 be the original Lorentz factor of a GRB's CBs[5] and $\gamma(t)$ its value after an observer's time t, diminishing as the CBs decelerate as a consequence of their interaction with the ISM ($t = 0$ is the GRB's trigger time). We have repeatedly reported in the literature the explicit form of the function $\gamma(t)$, a function of $\gamma(0)$ and x_∞, a charac-

[3] We are neglecting the initial CB's radius, presumably comparable or not much bigger than that of the collapsed core of the parent star, and thus entirely negligible by the time the GRB is emitted.

[4] To accommodate the possibly observed large GRB polarization, Lazzati et al. (2004) assume that the opening angle of their "fireball" ejecta is a few times $1/\gamma$, a completely ad-hoc choice, in their case.

[5] Unless otherwise stated, we approximate the theoretical form of the AG by the contribution of a single dominant CB.

teristic distance for the CB's slowdown (see, e.g. Dado et al. 2002). In the approximation of a constant-density ISM:

$$\begin{aligned}
\gamma \;&=\; \gamma(\gamma_0,\theta,x_\infty;t) = B^{-1}\;\left[\theta^2 + C\,\theta^4 + 1/C\right]\;,\\
C \;&\equiv\; \left[2/\left(B^2+2\,\theta^6+B\,\sqrt{B^2+4\,\theta^6}\right)\right]^{1/3}\;,\\
B \;&\equiv\; 1/\gamma_0^3 + 3\,\theta^2/\gamma_0 + 6\,c\,t/[(1+z)\,x_\infty]\,, \qquad (2)
\end{aligned}$$

with z the redshift of the host galaxy.

Let $\delta(t) \approx 2\,\gamma(t)/[1+(\gamma(t)\,\theta)^2]$ be the Doppler factor by which the energy of a photon is boosted by the CB's motion, at the viewing angle θ towards the observer (the approximation is for large γ, small θ, the domain of interest). An observer's time interval and the corresponding CB's travelled distance are related by $dx/c = dt\,\gamma(t)\,\delta(t)/(1+z)$. The very large typical values of the coefficient multiplying dt, of $\mathcal{O}(10^6)$ for small t, imply that CBs travel for kiloparsec distances in months of observer's time. The integrated distance travelled by CBs since their emission is $x = x_\infty\,[1/\gamma(t) - 1/\gamma(0)]$, typically of order a kiloparsec at t of order one week.

The contribution of the host galaxy to the polarization may be a complicated function of time, since the CBs are travelling for long distances and the line of sight from the CB to the observer is changing in length and in angular position in the sky. Both the degree and the direction of the induced polarization may be quite variable, since they depend on column-density-like integrals along the line of sight. Here we explore the simplest possibility by assuming for the host galaxy's contribution a constant polarization direction, $\chi_{_H}$, and arguing for an approximately exponentially-varying degree of polarization, $\Pi_{_H}$.

Since GRB progenitors are observed to populate the dense, central, actively star-forming regions of their host galaxies (Djorgovski et al. 2003), we shall make the approximation that the density of the ISM *dust* away from the parent SN decreases exponentially[6] with distance, with a characteristic fall-off length x_0 (we are avoiding the term "hight" because the CBs would typically travel in a slant direction relative to the normal to a galaxy's disk). The integrated host-galaxy column-density in the observer's direction (and the subsequent polarization) are then of the form:

$$\Pi_{_H}(t) = \Pi_0\,Exp\left[-\frac{x(t)}{x_0}\right] \equiv \Pi_0\,Exp\left[\frac{b}{\gamma_0}-\frac{b}{\gamma(t)}\right]\,, \qquad (3)$$

where $b \propto x_\infty/x_0$ is a parameter to fit. Because we are assuming a fixed polarization angle, $\chi_{_H}$, the Stokes parameters of the host-induced effect vary in the same way as $\Pi_{_H}$ does:

$$\begin{aligned}
Q_{_H}(t) \;&=\; Q_0\,\left[\frac{b}{\gamma_0}-\frac{b}{\gamma(t)}\right]\,,\\
U_{_H}(t) \;&=\; Q_{_H}(t)\,\tan 2\chi_{_H} \qquad (4)
\end{aligned}$$

[6] There is no contradiction with the constant density used in deriving Eq. (2), which refers to the bulk of the ISM at kpc distances and not the dust contamination at shorter distances.

6.5. The fitting procedure

The data on the time evolution of the optical and radio AG fluence at various frequencies is typically much more abundant than the data on the AG polarization. Given this, we first fit the fluence data, thereby extracting the parameters (γ_0, x_∞ and θ) that determine the function $\gamma(t)$ for each individual GRB. The way these fitting is performed is described in minute detail in Dado et al. (2003a). We subsequently fit the observed Stokes parameters Q and U to the sum the host-induced functions of Eq. (4) and their constant Galactic-induced values (except for GRB 030329, these values are those of the late-time measurements, introduced in the fits with their corresponding uncertainties). The polarization-fit parameters are Q_0, b, and $\chi_{_H}$. In the case of GRB 030329 and GRB 021004, the contribution of the two CBs are weighted according to their relative contribution to the optical light curves as function of time.

7. GRBs 020405, 020813, 021004 and 030329

These GRBs are the ones for which there is data on the time-dependence of the polarization of the AG. Their parameters describing our best fits to the AG fluence and polarization are given in Table I, where we have reported the polarizations levels and angles, rather than the Stokes parameters.

Table I: Inputs and parameters of the CB-model description of the AG fluence and polarizations of GRBs 020405, 020813, 021004 and 030329. γ_0, x_∞ and θ describe the AG fluence and determine $\gamma(t)$ via Eq. (2). The host-galaxy effect is described by the initial polarization level Π_0, its exponential decay constant b, and the polarization angle $\chi_{_H}$. But for the last GRB, whose AG is fit with two CB contributions, the Galactic (or late-time) parameters, $\Pi_{_G}$ and $\chi_{_G}$, are inputs.

Parameter	0405	0813	1004	0329
z	0.69	1.2545	2.328	0.1685
γ_0	645	1173	1403; 1259	1037; 1606
x_∞[Mpc]	0.31	0.54	0.025; 0.62	0.033; 0.37
θ [mrad]	0.42	0.14	1.47; 1.47	2.20; 2.30
Π_0 [%]	1.93	4.45	1.036	4.29
b	19.02	2005	128	4342
$\chi_{_H}$ [deg]	144	145	138	121
$\Pi_{_G}$ [%]	1.10	0.55	0.64	0.52
$\chi_{_G}$ [deg]	24.2	177	11.4	51.6

The CB-model fits to the NIR-optical AG light curves (which in all cases but that of GRB 020405 are a subset of a broader-band fit including radio data) are given in Figs. (1) to (4). The fit to GRB 020813 is new, all others have been previously published or posted in the Archives

(020405, 021004, 030329: Dado et al. 2002b, 2003b, 2004, respectively). The fits to the observed AG polarization and angle are shown in Figs. (5) to (12).

8. Discussion and conclusions

Examining the results shown in Figs. (5) to (12), we conclude that, for GRBs 020405, 020813 and 021004, the fits —which did not include an *intrinsic* polarization of the light emanating from the CBs— are good enough to conclude that this contribution vanishes within errors. As required in that case, the polarization and angle tend at late times to the Galactic foreground values. This is particularly convincing for GRB 020813. The most naive expectation —that the observed polarization simply reflects the foreground effects of the host galaxy and ours— is vindicated.

The case of GRB 030329, for which the data are particularly precise and abundant, brings havoc to the previous clear and simple conclusion. This is the case even if one neglects the data after day ~ 6, probably contaminated by the parent SN, which is particularly prominent in this instance.

In the CB-model, the explanation for the "humps" in the AGs of some GRBs, such as GRBs 970508 and 000301c (Dado et al. 2002a) and 030329 itself (Dado et al. 2004), is simple: the optical fluence $F_\nu(t)$ is a direct and *quasi-local* tracer of the density of the ISM through which a CB travels: spatial changes in density translate into temporal changes in fluence. This statement is not as sterile as it sounds, for it permits the extraction of the circumburst density and its radial profile from the time-dependence of the early AGs and, very satisfactorily, the magnitude and $\sim 1/r^2$ profile of the result are those expected from observations of "winds" of "pre-supernova" massive stars (Dado et al. 2003b).

In the case of GRB 030329, the observed deviations of the AG light curves from smoothly-varying functions are attributed to density fluctuations encountered by the CBs at the time they exit from the superbubble in which the explosion took place. The size and shape of these density fluctuations can be explicitly extracted from the data: they are a series of density jumps followed by $\propto 1/r^2$ declines, as befits the remnants of the explosions that created the superbubble (Dado et al. 2004). Their magnitude and shape (as functions of time) are shown in Fig. (13).

Fluctuations of the host's ISM density though which a CB travels may also cause the polarization fluctuations observed in GRB 030329. This may be a foreground "integral" effect (induced by the varying amounts and field directions of magnetized dust in the complicated density profile along the line of sight to the observer). It may also be a local "intrinsic" effect: the magnetic field within a CB may not be, at the few percent level, totally chaotic. It may be influenced by fluctuations in the density of the ISM particles that impinge into it and generate its magnetic structure. There appears to be no clearly convincing correlation between the fluctuations in the fluence and those in the polarization, though the periods of rapid variability coincide: compare Figs. (11) and (12) to Fig. (13). This inclines the balance somewhat in favour of an integral foreground effect, as if indeed there were no intrinsic polarization in the radiation emanating from the CBs, as expected for synchrotron radiation in a thoroughly disordered magnetic field.

Admittedly, the considerations of the previous paragraph are not simple and robust. They drive the conclusion that, in the CB model, no much is to be learned from the polarization of optical AGs. This is in contrast to the polarization of the γ-rays of a GRB, which, we contend, is crucial for deciding what the GRB-generating mechanism is: inverse Compton scattering if the polarization is measurably large.

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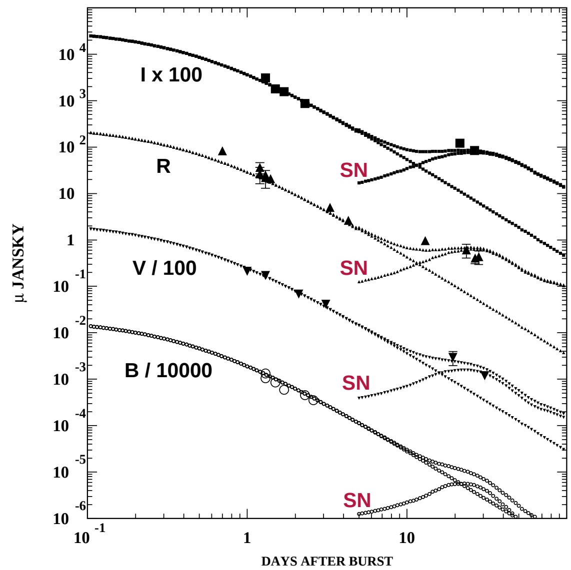

Fig. 1. CB model fit to the measured I, R, V, and B-band AG of GRB 020405. The various bands are scaled for presentation (see Dado et al. 2002a for details). The observations are not corrected to eliminate the effect of extinction, thus the theoretical contribution from a SN1998bw-like supernova was dimmed by the known extinction in the Galaxy and our consistently estimated extinction in the host. The contribution of the host galaxy, subtracted from the data by the HST observers, is not included in the fit.

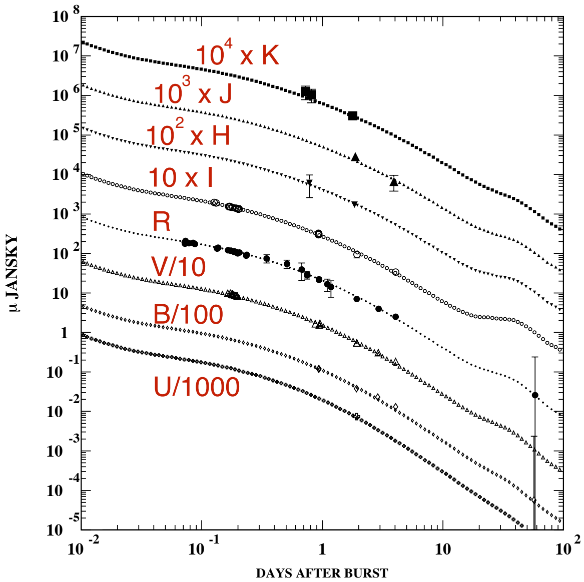

Fig. 2. Comparison between the observations in the K, J, H, I, R, V, B and U bands of the optical afterglow of GRB 020813 (Covino et al. 2003b, Li et al. 2003, Urata et al. 2003, and Gorosabel et al. 2003), and the CB model fit assuming one dominant CB (for details see e.g. Dado et al. 2003b). The various bands are rescaled for presentation.

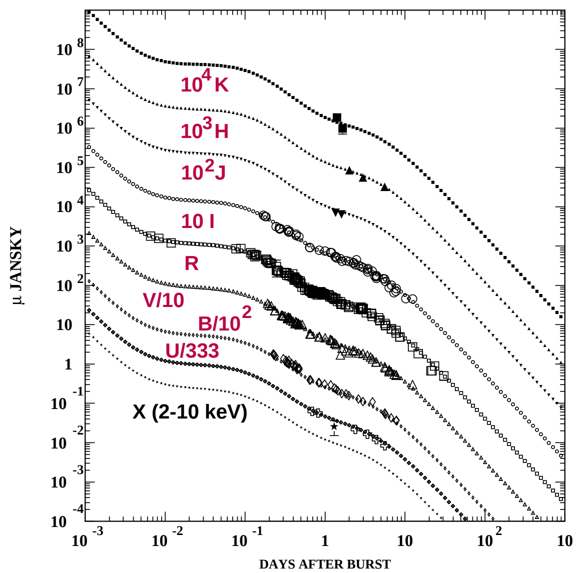

Fig. 3. The NIR–optical observations of the AG of GRB 021004 and the fit for two CBs with different parameters, corrected for extinction. The ISM density is a constant plus a "wind" contribution decreasing as $1/r^2$. The various bands are scaled for presentation. The data are those reported to date, in GCN notices (recalibrated with the observations of Henden et al. 2002), and in Bersier et al. (2002); Holland et al. (2002). The host-galaxy's contribution was subtracted from the late-time I, R and V data, where it is significant. The X-ray Datum is from Sako et al. (2002).

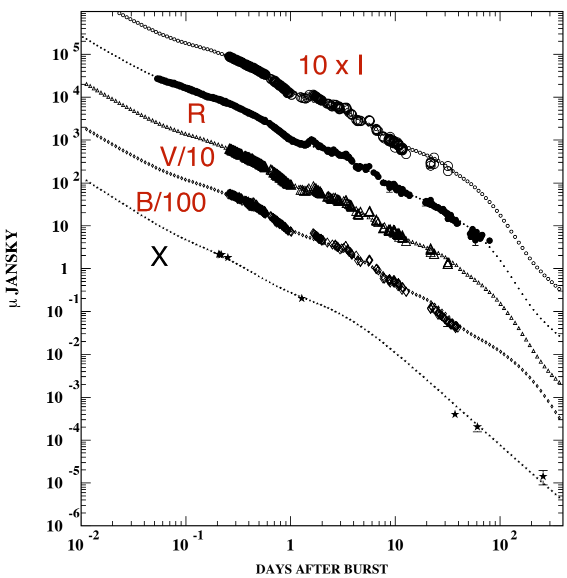

Fig. 4. The NIR–optical and X-ray observations of the AG of GRB 030329 and a broad-band fit for two CBs with different parameters, described in the Dado et al. (2002). The ISM density is assumed to be a constant plus a "wind" contribution decreasing as $1/r^2$. The various bands are scaled for presentation. The fit is to the X-ray data of RXTE (Marshall & Swank, 2003; Marshall, Markwardt & Swank, 2003) and XMM-Newton (Tiengo et al. 2003) and many other NIR-optical measurements, recalibrated by Lipkin et al. (2003 and references therein); as well as the radio data of Sheth et al. (2003) and Berger et al. (2003b). The host-galaxy's contribution was neglected. The individual bands have been rescaled for clarity.

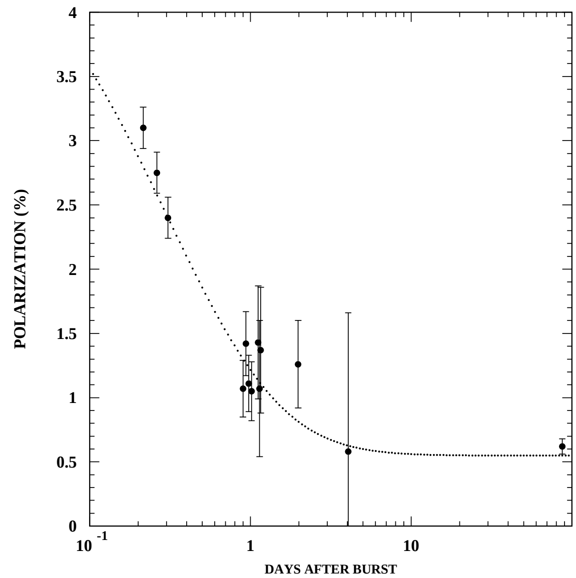

Fig. 5. Comparison between the linear polarization of the optical AG of GRB 020813 measured by Gorosabel et al. 2003 and the CB model fit assuming the polarization is *extrinsic*: produced by scattering of light by dust in the ISM along the line of sight in the host galaxy and in the Milky Way. The point at 100 days is the polarization of starlight in the Milky Way along the line of sight.

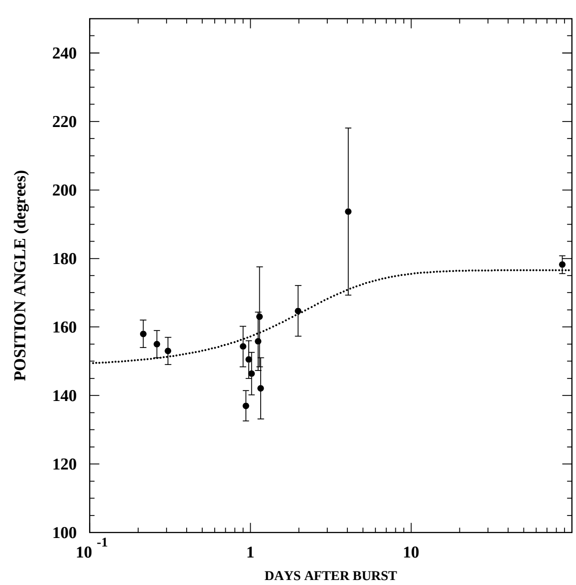

Fig. 6. Comparison between the position angle of the linear polarization of the optical AG of GRB 020813 measured by Gorosabel et al. (2003) and the CB model fit assuming the linear polarization is *extrinsic*. The point at 100 days is the position angle of the polarization of starlight in the Milky Way along the line of sight.

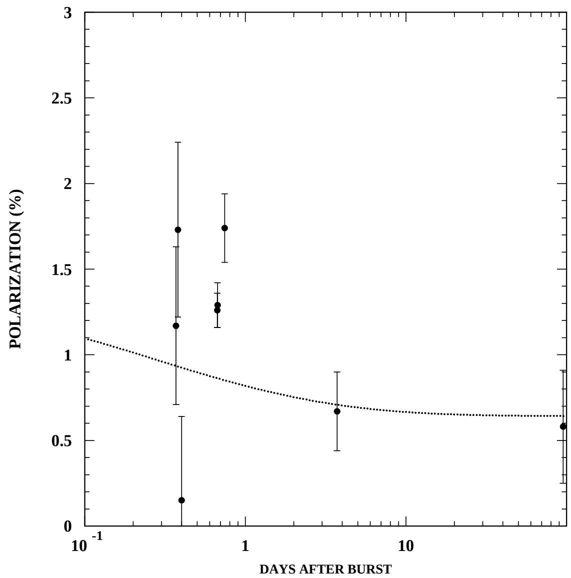

Fig. 7. Comparison between the linear polarization of the optical AG of GRB 021004 measured by Rol et al. (2003) and Wang et al. (2003), and the CB model fit assuming the polarization is *extrinsic*. The point at 100 days is the polarization of starlight in the Milky Way along the line of sight.

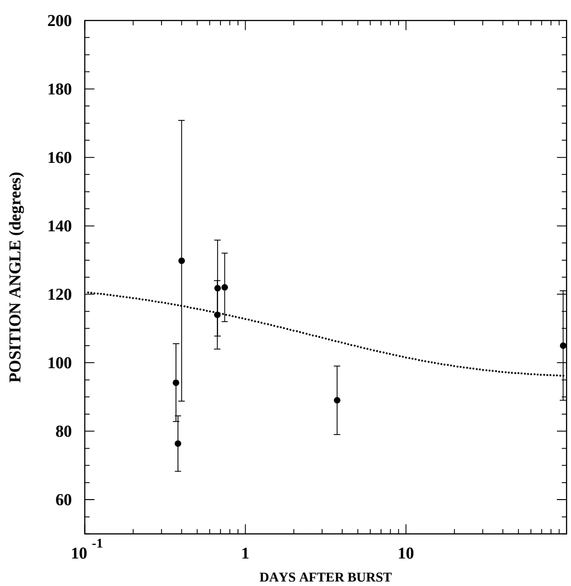

Fig. 8. Comparison between the position angle of the linear polarization of the optical AG of GRB 021004 measured by Rol et al. (2003) and Wang et al. (2003), and the CB model fit assuming the linear polarization is *extrinsic*. The point at 100 days is the position angle of the polarization of starlight in the Milky Way along the line of sight.

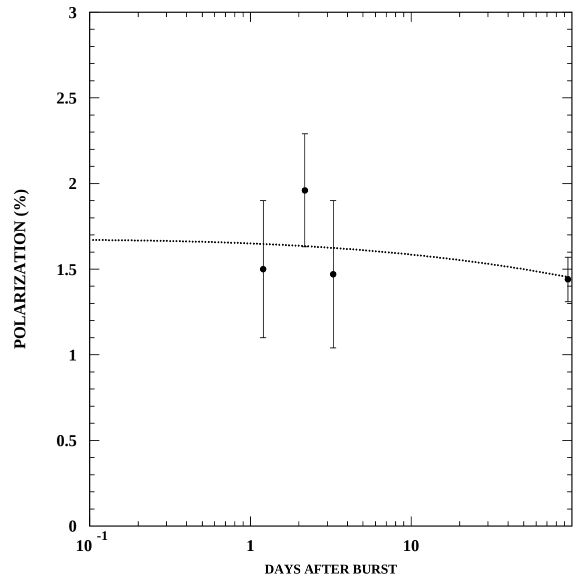

Fig. 9. Comparison between the linear polarization of the optical AG of GRB 020405 measured by Bersier et al. (2002); Masetti et al. (2003); Covino et al. (2003a), and the CB model fit assuming the polarization is *extrinsic*. The point at 100 days is the polarization of starlight in the Milky Way along the line of sight.

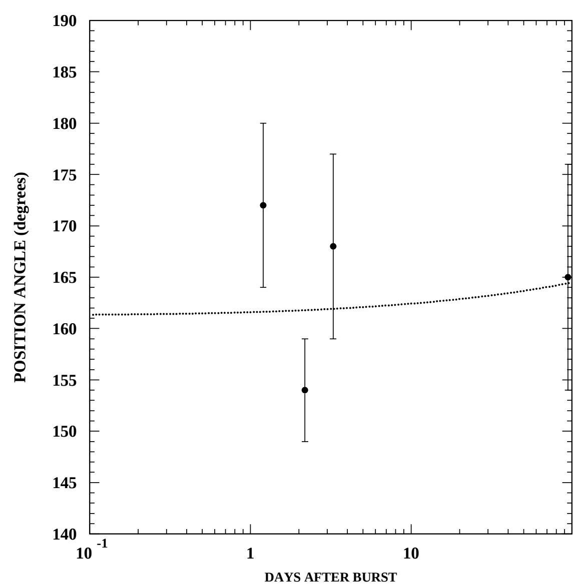

Fig. 10. Comparison between the position angle of the linear polarization of the optical AG of GRB 020405 measured by Bersier et al. (2002); Masetti et al. (2003); Covino et al. (2003a), and the CB model fit assuming the linear polarization is *extrinsic*. The point at 100 days is the position angle of the polarization of starlight in the Milky Way along the line of sight.

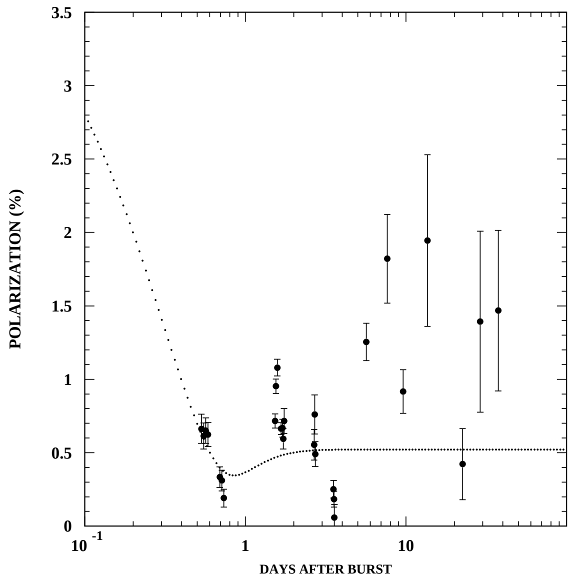

Fig. 11. Comparison between the linear polarization of the optical AG of GRB 030329 measured by Efimov et al. (2003), Magalhaes et al. (2003), Covino et al. (2003c) and Greiner et al. (2003), and the CB model fit assuming no *intrinsec* polarization and a host-induced polarization simply described by Eq. (3). The ansatz clearly fails.

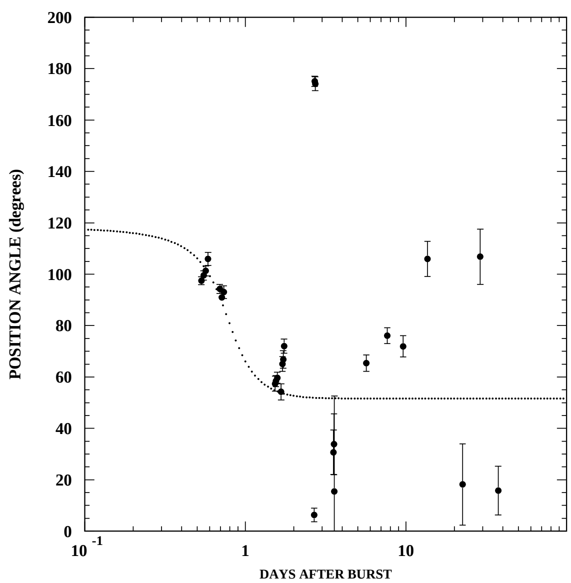

Fig. 12. Comparison between the position angle of the linear polarization of the optical AG of GRB 030329 measured by Efimov et al. (2003), Magalhaes et al. (2003), Covino et al. (2003c) and Greiner et al. (2003), and the CB model fit assuming no *intrinsic* polarization and a host-induced polarization simply described by Eq. (3). The ansatz clearly fails.

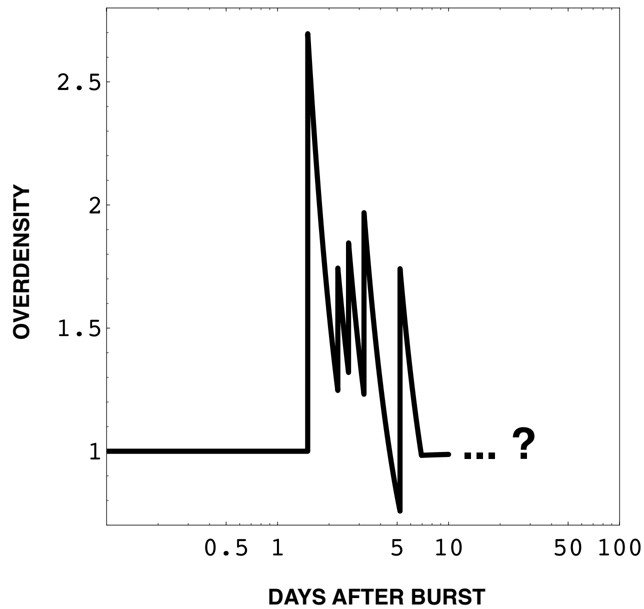

Fig. 13. The overdensity (relative to a smoothly varying function) of the ISM traversed by the CBs of GRB 030329 (Dado et al. 2004), shown as a function of observer's time, for comparison with the polarization results of Figs. (11,12). The fit to the AG does not determine the density for $t > 10$ days, a time at which the observations are dominated by the associated SN.